International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 8, Issue 6, Dec 2018, 201-206

AN AXIAL CRUSHING CHARACTERISTICS OF HYBRID KENAF/GLASS FABRIC WRAPPED ALUMINIUM CAPPED TUBES UNDER STATIC LOADING

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ABSTRACT

Thin-walled tubular members are frequently used as energy absorbing elements in modern vehicles which can protect occupants during impact collisions. These tubular energy absorbing devices are once plastically deformed, they are discarded and exchanged. Thus, the design constraint for such element is generally to attain excellent specific energy absorption with light weight, while keeping the crushing force low enough to reduce the injury to the occupants and damage to the vehicle. Metal tubes with wrapped fabric, polymer composites are one such device with outstanding specific energy absorption capacity and mean crushing force compared with the metal tubes and hence proposed. Therefore, this research article investigates the axial crushing and specific energy absorption characteristics of hybrid kenaf/glass fabric wrapped aluminium capped tubes through static experiments. The proposed tubes comprise of a cylindrical segment with plain end cap, shallow-spherical cap and hemispherical cap, which were manufactured by a multi-stage deep drawing process. Hybrid aluminium-composite tubes were prepared by wrapping fabrics over the aluminium tubes by hand-lay-up method. The static crushing behaviour and energy absorption characteristics of various tube configurations were examined experimentally. Moreover, the crashworthiness performance of the proposed hybrid tube was compared with plain aluminium tubes and the results revealed that the specific energy absorption capacity of the hybrid tube is 15-35% greater than the plain aluminium tube. As a result, the present research article emphasized the advantages of using hybrid tubes so as to improve the crashworthiness characteristics of energy absorbing elements in automotive vehicles.

KEYWORDS: Crash Worthiness, Composite Wrapped Tube, Energy Absorbers, Passive Safety, Static & Crushing

Received: Aug 24, 2018; **Accepted:** Sep 14, 2018; **Published:** Oct 27, 2018; **Paper Id.:** IJMPERDDEC201824

Original Article

INTRODUCTION

Thin-walled tubular structures have been broadly employed as impact, energy absorbing members to reduce the harmful effects of an impact force during collisions and consequently enhance the crash performance of a structure [1, 2]. The most important characteristics that affect the energy absorption capacity of such tubular members are geometry, material and applied loading conditions respectively. Some of the important crashworthy parameters to be considered while designing the energy absorbers are Energy absorption capacity, Initial peak force, Mean crushing force and Specific energy absorption of the tubes. The materials used for manufacturing the thin-walled tubes are metals and composites. The energy absorbing mechanisms of metallic and composite structures are significantly different. The structures made from metallic materials are generally ductile which allows them to dissipate the kinetic energy through continuous plastic deformation [3] while the brittle nature of

composite structures dissipate energy through different combined fracture mechanisms such as matrix cracking, delamination, and fiber breakage [4].

The composite tubular structures absorb superior energy per unit mass than the metallic tubes such as aluminium and mild steel. Various natural fabrics such as kenaf, flax, sisal, and jute have been utilized in structural engineering applications owing to their bio-degradability, less cost, high specific strength, and eco-friendliness. Several researchers in the past have studied the mechanical and crashworthiness properties of natural fabric reinforced polymer composites [5, 6]. However, the crashworthiness design and analysis of the natural composite tube as energy absorbing devices are challenging due to nature of brittle fracture and their orthotropic properties. A number of previous investigations have evaluated the importance of the hybrid structures that include both types of material, i.e. metal and composites, to absorb a larger amount of impact energy such as composite wrapped metal tubes [7, 8]. The hybrid tube structures combine the desired properties of each material, ductility and stable plastic deformation mode of the metals and the high ratio of strength to weight of the composites. For example, Mallick [10] examined the crashworthiness performance of hybrid circular tubes containing aluminium tubes overwrapped with filament-wound glass fabric reinforced polymer. The results revealed that the hybrid tubes have substantial influence on higher energy absorption than either the aluminium tubes or the composite tubes. Zhu et al. [11] investigated the axial crushing behaviour of hybrid aluminium/CFRP which was related with plain aluminium tube and CFRP tube to explore comparable patterns and crushing behaviours of the tube under static loading. Moreover, the study of hybrid composite in energy absorption capability of tubes such as synthetic/synthetic fabric reinforced polymer and metal/synthetic fabric reinforced polymer predicted that the hybridization effect will enhance the crashworthiness characteristics and amount of energy absorbed, therefore the concept of hybridization from other fabric such as hybrid natural/synthetic will promote the research study on the novel stages of improvement into excellent energy absorption [11, 12].

Furthermore, it is deduced that hybrid composite wrapped metal tubes provide a new structural configuration to meet increasing lightweight and crash worthiness requirements in automobile industry. However, these existing research studies have mainly focused on the hybrid non-capped cylindrical tubes that induce high initial peak force which has the potential to cause heavy damage to occupants and the vehicle during impact crash events. Hence, in this paper, hybrid capped cylindrical tubes with low initial peak force are proposed as energy absorbing elements when subjected to axial static loading conditions. The static crash performance of the glass/kenaf fabric wrapped combined geometry tubes are compared with the glass/kenaf fabric wrapped open cylindrical tube and it was found that the initial peak force of the proposed tubes significantly reduced by 15-35% approximately. Overall results revealed that the hybrid capped cylindrical tubes can reduce the initial peak force without compromising the energy absorbing capacity and could be used as an impact energy absorbing elements in automotive vehicles respectively.

EXPERIMENTS

Initially, the capped cylindrical segment of the hybrid tube was fabricated from commercial aluminium sheet of thickness 1.63 mm using a multi-stage deep drawing process. A four-stage drawing process was designed using an automated design calculating system developed by the researchers [13] to manufacture a capped cylindrical tube. After the effective fabrication of aluminium tubes of desired geometry, the kenaf/glass fabric wrapped aluminium tubes were fabricated by wrapping two layers of glass/kenaf/epoxy prepreg around cylindrical tube followed by the curing process under the room temperature for 48 hours. Figure 1 shows the geometrical dimensions of the hybrid capped cylindrical tube

specimens used.

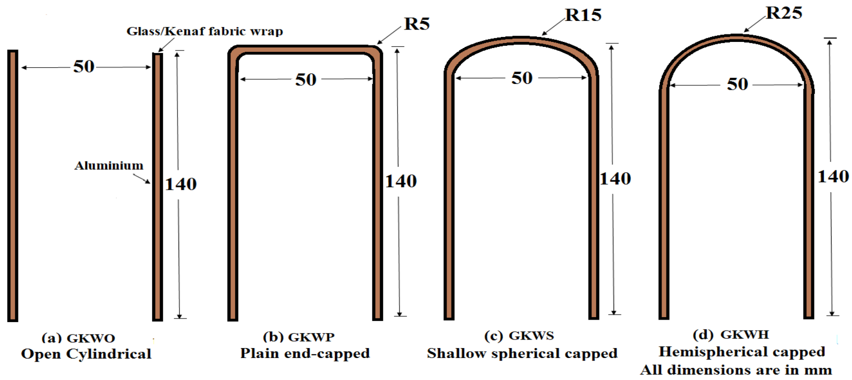

Figure 1: **Dimensions of the Hybrid Tube Specimens**

The crushing experiments were performed on the fabricated composite wrapped capped cylindrical tube specimens using a computerized Universal Testing Machine (UTM) at a velocity of 5 mm/min under static loading conditions. The machine recorded the displacement of the compressor head and the crushing force concurrently using the Data Acquisition System that is linked from the UTM to the computer. Three specimens were tested for each configuration to check the repeatability and data precision. The difference in the initial peak force between three specimens was about 6%, which is tolerable. The crushing behaviour of the end-capped hybrid tubes was characterized by determining the crashworthiness parameters [14] such as Crushing Length (CL), initial Peak Force (IPF), Mean Crushing Force (MCF), Energy Absorption Capacity (EAC) and Specific Energy Absorption (SEA) from the relevant axial force-displacement plots of every specimen for hybrid capped cylindrical tube specimens respectively as displayed in Table 1.

Table 1: **Quasi-Static Test Results**

Type	Geometry	Mass (g)	C L (mm)	IPF (kN)	MCF (kN)	EAC (J)	SEA (J)
GKWO	Glass/Kenaf wrapped Non-capped (open)	150	70	29	20	1395	18.00
GKWP	Glass/Kenaf wrapped plain end-capped	156	70	23.78	20.42	1430	17.88
GKWS	Glass/Kenaf wrapped shallow spherical end-capped	145	70	22.9	18	1261	16.07
GKWH	Glass/Kenaf wrapped hemispherical end-capped	144	70	21	17.85	1249	16.01

RESULTS AND DISCUSSIONS

In the present investigation, four types of hybrid composite wrapped tube geometry were considered as crushing energy absorber under quasi-static loading conditions and the detailed outcomes of the experimental work were presented. The crushing modes of the tested samples were also analysed from photography. Which display the comparison of final crushed patterns obtained from the axial crushing test of all hybrid combined geometry tube is displayed in Figure 3. The most important energy absorbing mechanisms observed in this study is Matrix cracking, delamination, progressive crushing, fabric micro-buckling and fracture. When the GKWO tubes were axially crushed, they showed the progressive deformation mode in the aluminium segment and detrimental fracture mode with a stable crushing force in the composite wrap respectively. The crushing force during initial phases showed a sudden growth and propagation of longitudinal cracks at its major width due to high stress concentration. The fold formation has become critical as the overwraping of glass fabric layer. The stationary cracks were developed at the mid positions from one roving to another. This phenomenon, known as the longitudinal segment of composite material experienced post–mixed crushing mode.

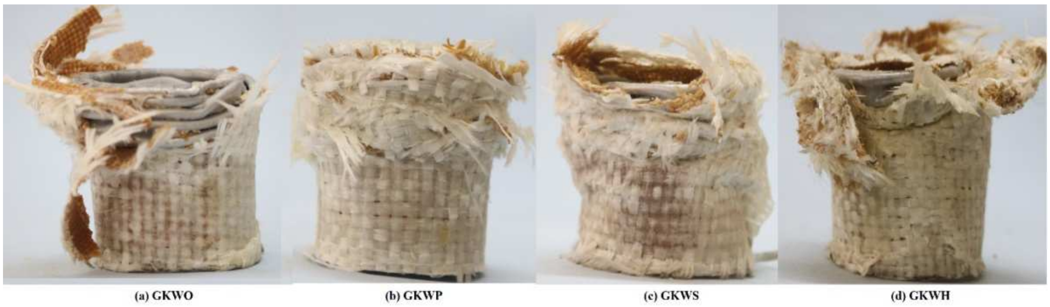

Figure 2: Final Crushed Shapes of Glass/Kenaf Fabric Wrapped Hybrid Tubes

When GKWP, GKWS, and GKWH tube specimens were crushed under same static loading conditions similar crushing modes with inward dimpling was witnessed. The fillet radius of the capped cylindrical tube is directly proportional to the inward dimpling length. In case of crushing GKWP tubes, the initial fold is occurring in the fillet region due to the separation of the upper rigid surface from the end-capped surface. The crushing force reaches to a maximum value when the initial fold is formed. However, the maximum crushing force obtained in GKWP tubes was less than the GKWO tube. The progressive folding with micro fracture of composite layers was witnessed in the cylindrical wall as the cyclical outer and inner radial displacements.

The comparative results of axial crushing force versus deformation and energy absorption characteristics of the glass fabric wrapped capped cylindrical tube obtained from the static experimental results are shown in Figure 3. It is observed that GKWP tubes results the decrease in initial peak force by 18%, whereas the GKWH tubes further improved it by 28%. The highest value of energy absorption capacity was obtained in GKWP tubes of 1430 J due to increase in crushing force carrying capacity. The results revealed that GKWO tubes displayed a high initial peak force followed by lower fluctuating mean crushing force, whereas (GKWP, GKWS, and GKWH) capped tubes showed a gradual increase in crushing force until the initial peak force followed by an increase in the successive mean crushing forces. The static crushing results showed that composite wrapped aluminium capped cylindrical tubes could be utilized effectively to enhance the axial crushing characteristics and energy absorbing capacity of the aluminium cylindrical tubes. Also, it is clear from the results, that the composite wrapped capped cylindrical tubes have higher crushing force and energy absorption capacity than the bare aluminium tubes [15]. Hence, these proposed composite wrapped capped cylindrical tubes could be the optimum choice in the design of the energy absorbing system for any vehicle.

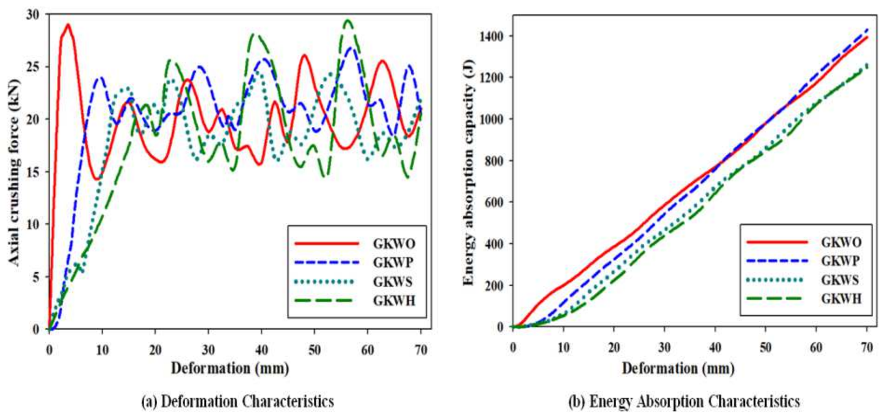

Figure 3: Static Crushing Characteristics of Kenaf/Glass Fabric Wrapped Hybrid Tubes

CONCLUSIONS

In this research article, the axial crushing characteristics of glass/kenaf/epoxy composite wrapped capped cylindrical tubes were examined, in order to design optimum energy absorber of the automobile that could increase the safety of occupants as well as reduce weight of the structure during impact collisions. The static crushing test results revealed that the crashworthiness parameters of the aluminium capped cylindrical tubes strongly effected by composite wrappings. The main conclusions from this research study are summarized below.

- The comparison of deformation modes in non-capped and capped cylindrical tubes reveals that the deformation modes of conventional cylindrical tubes can be modified by harnessing cap at the end.
- The static crash performance of the glass/kenaf fabric wrapped combined geometry tubes are compared with the glass/kenaf fabric wrapped open cylindrical tube and it was found that the initial peak force of the proposed tubes significantly reduced by 15-35%.
- The significant outcomes related to the hybrid tubes highlighted the advantages of using combined methods such as capped ends and composite wraps in enhancing the crashwothiness characteristics of energy absorbers and to design a convenient crash protection system for absorbing impact energy during vehicle collision events.

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